

FORM PTO-1390
(REV. 5-93)U.S. DEPARTMENT OF COMMERCE
PATENT AND TRADEMARK OFFICEATTORNEY'S DOCKET NUMBER
2345/159**TRANSMITTAL LETTER TO THE UNITED STATES
DESIGNATED/ELECTED OFFICE (DO/EO/US)
CONCERNING A FILING UNDER 35 U.S.C. 371**

U.S. APPLICATION NO. (If known, see 37 CFR 1.5)

09/890597INTERNATIONAL APPLICATION NO.
PCT/EP00/00320INTERNATIONAL FILING DATE
**17 January 2000
(17.01.00)**PRIORITY DATE CLAIMED:
**03 February 1999
(03.02.99)**TITLE
REDUCTION OF THE DISTORTION OF OPTICAL IMPULSES THROUGH POLARISATION MODE DISPERSION IN OPTICAL TRANSMISSION SYSTEMSAPPLICANT(S) FOR DO/EO/US
DULTZ, Wolfgang; BERESNEV, Leonid; FRINS, Erna; KUEPPERS, Franko; SCHMITZER, Heidrun; VOBIAN, Joachim; and WEIERSHAUSEN, Werner

Applicant(s) herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) immediately rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
 - a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☒ has been transmitted by the International Bureau.
 - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US)
6. ☒ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
 - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☐ have been transmitted by the International Bureau.
 - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
 - d. ☒ have not been made and will not be made.
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)). (UNSIGNED)
10. ☒ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern other document(s) or information included:

11. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☒ A **FIRST** preliminary amendment.
☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
14. ☒ A substitute specification and a marked up version of the substitute specification.
15. ☐ A change of power of attorney and/or address letter.
16. ☒ Other items or information: International Search Report; International Preliminary Examination Report; and Form PCT/RO/101.

Express Mail No.: EL244503832

U.S. APPLICATION NO. **09/890597**

INTERNATIONAL APPLICATION NO
PCT/EP00/00320

ATTORNEY'S DOCKET NUMBER
2345/159

17. ☒ The following fees are submitted:

Basic National Fee (37 CFR 1.492(a)(1)-(5)):

Search Report has been prepared by the EPO or JPO \$860.00

International preliminary examination fee paid to USPTO (37 CFR 1.482) \$690.00

No international preliminary examination fee paid to USPTO (37 CFR 1.482) but
international search fee paid to USPTO (37 CFR 1.445(a)(2)) \$710.00

Neither international preliminary examination fee (37 CFR 1.482) nor international
search fee (37 CFR 1.445(a)(2)) paid to USPTO \$1,000.00

International preliminary examination fee paid to USPTO (37 CFR 1.482) and all
claims satisfied provisions of PCT Article 33(2)-(4) \$100.00

CALCULATIONS | PTO USE ONLY

ENTER APPROPRIATE BASIC FEE AMOUNT = \$ 860

Surcharge of \$130.00 for furnishing the oath or declaration later than ☐ 20 ☐ 30 months
from the earliest claimed priority date (37 CFR 1.492(e)).

\$

Claims	Number Filed	Number Extra	Rate		
Total Claims	12 - 20 =	0	X \$18.00	\$0	
Independent Claims	2 - 3 =	0	X \$80.00	\$0	
Multiple dependent claim(s) (if applicable)			+ \$270.00	\$	

TOTAL OF ABOVE CALCULATIONS = \$860

Reduction by 1/2 for filing by small entity, if applicable. Verified Small Entity statement must
also be filed. (Note 37 CFR 1.9, 1.27, 1.28).

\$

SUBTOTAL = \$860

Processing fee of \$130.00 for furnishing the English translation later the ☐ 20 ☐ 30
months from the earliest claimed priority date (37 CFR 1.492(f)).

\$

TOTAL NATIONAL FEE = \$860

Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be
accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). \$40.00 per property

\$

TOTAL FEES ENCLOSED = \$860

Amount to be
refunded
charged

\$
\$

- a. ☐ A check in the amount of \$_____ to cover the above fees is enclosed.
- b. ☒ Please charge my Deposit Account No. 11-0600 in the amount of \$860.00 to cover the above fees. A duplicate copy of this
sheet is enclosed.
- c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to
Deposit Account No. 11-0600. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or
(b)) must be filed and granted to restore the application to pending status.

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NAME

DATE

CUSTOMER NO. 26646

09/890597
JC05 Rec'd PCT/PTO 03 AUG 2001

2345/159
EXPRESS MAIL CERTIFICATE

"EXPRESS MAIL" MAILING LABEL NUMBER EL244503832

DATE OF DEPOSIT 8/3/01

TYPE OF DOCUMENT Nat'l Phase App. of Dultz's et. al.
"Reduction of the Distortion of optical Impulses..."

SERIAL NO. To be Assigned FILING DATE Herewith

I HEREBY CERTIFY THAT THIS PAPER OR FEE IS BEING DEPOSITED WITH THE UNITED STATES POSTAL SERVICE "EXPRESS MAIL POST OFFICE TO ADDRESSEE" SERVICE UNDER 37 CFR 1.10 ON THE DATE INDICATED ABOVE, BY BEING HANDED TO A POSTAL CLERK OR BY BEING PLACED IN THE EXPRESS MAIL BOX BEFORE THE POSTED DATE OF THE LAST PICK UP, AND IS ADDRESSED TO THE ASSISTANT COMMISSIONER FOR PATENTS, WASHINGTON, D.C. 20231.

DAVID POSTOLSKI
(PRINTED NAME OF PERSON MAILING PAPER OR FEE)

[Signature]
(SIGNATURE OF PERSON MAILING PAPER OR FEE)

10 Rec

63 AUG 2001

[2345/159]

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s) : Wolfgang DULTZ et al.
Serial No. : To Be Assigned
Filed : Herewith
For : REDUCTION OF THE DISTORTION OF OPTICAL
IMPULSES THROUGH POLARISATION MODE
DISPERSION IN OPTICAL TRANSMISSION SYSTEMS
Art Unit : To Be Assigned
Examiner : To Be Assigned

Assistant Commissioner
for Patents
Washington, D.C. 20231

**PRELIMINARY AMENDMENT AND
37 C.F.R. § 1.125 SUBSTITUTE SPECIFICATION STATEMENT**

SIR:

Please amend without prejudice the above-identified application before
examination, as set forth below.

IN THE TITLE:

Please replace the title with the following:

--REDUCING THE DISTORTION OF OPTICAL PULSES CAUSED BY POLARIZATION
MODE DISPERSION IN OPTICAL COMMUNICATION SYSTEMS--.

IN THE SPECIFICATION AND ABSTRACT:

In accordance with 37 C.F.R. § 1.121(b)(3), a Substitute Specification
(including the Abstract, but without claims) accompanies this response. It is respectfully
requested that the Substitute Specification (including Abstract) be entered to replace the
Specification of record.

EL244503832

The Substitute Specification reflects the text of Revised Pages 1, 2, 2a, 2b, 16, 17, and 18, associated with the International Preliminary Examination Report.

IN THE CLAIMS:

Without prejudice, please cancel original claims 1 to 12 in the original application and please cancel substitute claims 1 to 12 from the Revised Pages, and please add new claims 13 to 24 as follows:

13. (New) A method for reducing distortion of an optical pulse contained in a communication-transmitting luminous flux in an optical communication system caused by polarization mode dispersion, comprising:

driving a polarization-controlling device to adjust a polarization of the optical pulse so that a transmission quality of the optical communication system is maximized, wherein the driving of the polarization-controlling device functions in response to the transmission quality detected; and

using a small, coupled-out portion of the communication-transmitting luminous flux to determine the transmission quality of the optical communication system.

14. (New) The method of claim 13, further comprising:

resetting the polarization of the optical pulse in predefined time intervals for optimizing communication.

15. (New) The method of claim 13, wherein the polarization of the optical pulse is controlled at an input end of the optical communication system.

16. (New) The method of claim 13, further comprising:

altering the polarization of the optical pulse at an output end of the optical communication system using the polarization-controlling device,

wherein the optical pulse propagates through an analyzer following the optical communication system.

17. (New) An optical communication system having reducible distortion of an optical pulse propagating through the optical communication system and contained in a communication-transmitting luminous flux, comprising:

- an optical transmission medium for transmitting the optical pulse;
- a determining device to determine a transmission quality of the optical communication system, the determining device having an output;
- a polarization-controlling device;
- a regulating device having an input;
- a beam splitter for coupling out and supplying a small portion of the communication-transmitting luminous flux to the determining device;

wherein a signal from the output of the determining device is applied to the input of the regulating device, and

wherein the regulating device is configured to drive the polarization-controlling device for changing a polarization of the optical pulse so that the transmission quality is optimized.

18. (New) The optical communication system of claim 17, wherein the polarization-controlling device is disposed at the input of the optical transmission medium.

19. (New) The optical communication system of claim 17, further comprising:

- an analyzer, the analyzer being disposed in a propagation direction of a light, downstream from the polarization-controlling device; and

wherein the polarization-controlling device is disposed at the output of the optical transmission medium.

20. (New) The optical communication system of claim 17, wherein the polarization-controlling device includes a first $\lambda/4$ delay element, a $\lambda/2$ delay element and a second $\lambda/4$ delay element, the first $\lambda/4$, $\lambda/2$ and second $\lambda/4$ delay elements being disposed in series as $\lambda/4$ - $\lambda/2$ - $\lambda/4$ and being adjustable.

21. (New) The optical communication system of claim 19, wherein the analyzer is a linear analyzer, and the polarization-controlling device includes at least an adjustable $\lambda/4$ delay element and an adjustable $\lambda/2$ delay element.

22. (New) The optical communication system of claim 21, wherein at least one delay element includes a liquid crystal element.

23. (New) The optical communication system of claim 21, wherein at least one delay element includes an electro-optical crystal.

24. (New) The optical communication system of claim 21, wherein at least one delay element includes at least one of a mechanically adjustable element, an electromotively adjustable element and a piezoelectrically adjustable element of three fiber loops.

REMARKS

This Preliminary Amendment cancels without prejudice original claims 1 to 12 and substitute claims 1 to 12 in the underlying PCT Application No. PCT/EP00/00320, and adds without prejudice new claims 13 to 24. The new claims conform the claims to U.S. Patent and Trademark Office rules and do not add new matter to the application.

In accordance with 37 C.F.R. § 1.121(b)(3), the Substitute Specification (including the Abstract, but without the claims) contains no new matter. The amendments reflected in the Substitute Specification (including Abstract) are to conform the Specification and Abstract to U.S. Patent and Trademark Office rules or to correct informalities. As required by 37 C.F.R. § 1.121(b)(3)(iii) and § 1.125(b)(2), a Marked Up Version Of The Substitute Specification comparing the Specification of record and the Substitute Specification also accompanies this Preliminary Amendment. In the Marked Up Version, shading indicates added text and bracketing indicates deleted text. Approval and entry of the Substitute Specification (including Abstract) is respectfully requested. The Substitute Specification reflects the text of Revised Pages 1, 2, 2a, 2b, 16, 17, and 18, associated with the International Preliminary Examination Report.

The underlying PCT Application No. PCT/EP00/00320 includes an International Search Report, dated May 10, 2000. The Search Report includes a list of documents that were uncovered in the underlying PCT Application. A copy of the Search Report accompanies this Preliminary Amendment.

The underlying PCT Application No. PCT/EP00/00320 also includes an International Preliminary Examination Report, dated April 6, 2001, and an annex (including substitute claims 1 to 12 and the specification text of Revised Pages 1, 2, 2a, 2b, 16, 17, and

18, associated with the International Preliminary Examination Report). An English translation of the International Preliminary Examination Report and of the annex accompanies this Preliminary Amendment.

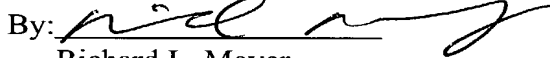
Applicants assert that the subject matter of the present application is new, non-obvious, and useful. Prompt consideration and allowance of the application are respectfully requested.

Respectfully Submitted,

KENYON & KENYON

By: 
BN 35952

Dated: 8/3/01

By: 

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JC05 Rec'd PCT/PTO 03 AUG 2001
09/890597

REDUCING THE DISTORTION OF OPTICAL PULSES CAUSED BY POLARIZATION MODE DISPERSION IN OPTICAL COMMUNICATION SYSTEMS

FIELD OF THE INVENTION

The present invention relates to a method for reducing the distortion of optical pulses in optical communication systems, and to an optical communication system having reduced spreading of the optical pulses propagating through the system.

BACKGROUND INFORMATION

In optical communications, optical components, such as optical elements and glass fibers, which are only isotropic in the first approximation or which are innately anisotropic are believed to be used. For example, the glass fibers employed in photonic networks may exhibit optical anisotropies due to the manufacturing process and design or due to other circumstances, such as temperature and pressure fluctuations, as well as because of the bending of the fiber itself. These, in part, location-dependent anisotropies may also produce an optical birefringence (or double refraction), which can also vary from location to location in the fiber. The birefringence (or double refraction) may result in two orthogonally polarized natural waves of the light propagating at a different phase velocity in one fiber section under consideration. When an optical signal, e.g., an optical pulse having any polarization, is transmitted through the fiber, the optical pulse is believed to become distorted, i.e., spreads during the course of propagation, due to the difference in the velocity of the various polarization components. This spreading of the optical pulses may limit the transmission rate in the communication system.

The reference of "Optical Equalization of Polarization

EL244503832

SUBSTITUTE SPECIFICATION

Dispersion", J.H. Winters et al., Proceedings of the STIE, January 1, 1992, discusses an optical equalizing system, which can be used to reduce the influences of polarization mode dispersion. It is believed that to generate the control signals for the polarization-controlling elements, the optical received signal is received in its entirety in one or a plurality of receivers and is analyzed accordingly. A further transmission of the optical signal is believed to be no longer possible.

The U.S. Patent No. 5,793,511 discusses an optical receiver having an equalizing circuit which is able to equalize an optical signal distorted by polarization mode dispersion. For this, the received optical signal is converted into two electrical components, of these, the equalizing circuit generating a quality signal for driving a polarization control element implemented in the receiver.

The European Patent Publication No. 0 716 516 discusses a polarization-diversity detection technique for optical signals transmitted over a single-mode fiber. To compensate for distortions caused by polarization mode dispersions in the fiber, a polarization-diversity detection is carried out. For this, it is believed that the optical received signal is initially separated by a polarization beam splitter into a first and second polarization component. A control signal is believed to be subsequently generated to control a polarization-control element as a function of the phase difference between the two polarization components.

SUMMARY OF THE INVENTION

An exemplary embodiment of the present invention is directed to providing a method for reducing the distortion of optical pulses in optical communication systems caused by polarization mode dispersion, which can be implemented cost-effectively, flexibly adapted to the particular optical communication

system, and which also allows for dynamic fluctuations with respect to the birefringence. Exemplary embodiments of the present invention are further directed to providing a suitable optical communication system in part which may effect the method for reducing the distortion of optical pulses in optical communication systems caused by polarization mode dispersion.

To keep the transmission quality in the optical communication system at an optimal value, the transmission quality is measured, and a signal indicative thereof is applied to a regulating device, which drives a polarization-controlling device to alter the polarization state of the communication-transmitting optical pulses. The regulating device controls the polarization of the optical pulses in such a way that the transmission quality is optimized. A small coupled-out portion of the communication-transmitting luminous flux may be used to determine the transmission quality.

Any transmission device at all, for example, an optical fiber or other optical component, can be composed with respect to its birefringence properties, of a number of double-refracting plates, each of which has a different, statistically varying birefringence, delay and orientation. A double-refracting plate assembly of this kind is characteristic for a specific wavelength and is, therefore, dependent upon the frequency of the incident light.

An actual glass fiber may be constituted of a plate assembly, which is not characterized by a stochastic system (or arrangement) of double-refracting plates, but rather that there is at least one preferred, i.e., substantially constant, birefringence in specific sections of the fiber. This means that the optical properties in the mentioned fiber sections can be specified by a single, thick and/or heavily double-refracting plate. An information signal, which

An exemplary embodiment of the present invention is directed to assuring that the optical pulse propagates within the optical communication system having at least one section with preferred or substantially constant birefringence, in such a way that, in the at least one section, the signal exhibits a polarization which corresponds to one of the two main polarization states of the section, e.g., a fiber member. As a result, the pulse shape may not be broadened during transmission by the section having preferred or substantially constant birefringence. Within the section having preferred birefringence, the optical pulses propagate only in one of the two possible channels, i.e., either in the channel having a high rate of propagation or in the channel having the slow rate of propagation, so that the optical pulses are not thereby split or widened, but only accelerated or delayed. This may have no adverse effect on the transmission rate, since the entire pulse sequence experiences an acceleration or delay. It is, thus, assured that the section of the optical transmission medium which exhibits a preferred or substantially constant birefringence and, therefore, may substantially contribute to the widening of the optical pulses, is "eliminated" with respect to the polarization mode dispersion within the entire communication system. The remaining broadening of the optical pulse may only still be caused by the remaining sections of the communication system,

which can be described, for example, as a stochastic system or arrangement of thin, double-refracting plates. However, the extent to which these other sections of the communication system cause the optical pulse to widen is much less than the possible distortion of the pulse within the section having preferred or substantially constant birefringence, for the case that the light does not traverse the last-mentioned section in only one of the main polarization states.

The exemplary embodiments of the present invention are directed to providing that when the optical pulses are modified by the polarization-controlling device before entering into the optical communication system, such that the section having preferred or substantially constant birefringence is traversed in one of the main polarization states of the section and when only that portion of the optical information signal which is transmitted in one of the main polarization states of the section having preferred or substantially constant birefringence, through this section, is considered for the data transmission. Both cases are based on the elucidated principle of the present invention and, accordingly, are equivalent.

To alter the polarization of the information signal in accordance with the present invention, the polarization-controlling device is driven by the regulating device in such a way that the transmission quality is maximized. This regulated, maximal transmission quality corresponds accordingly, for example, to the case when the optical information signal propagates within the section having preferred or substantially constant birefringence in one of the two main polarization states, or when only that portion of the optical information signal, which this applies to, is considered.

Another exemplary embodiment of the present invention is

directed to providing for repeatedly maximizing the transmission quality at spaced apart time intervals. The time-related fluctuations in the magnitude and orientation of the birefringence, which can have a negative effect on the distortion of the optical pulses can be diminished. These fluctuations, induced, for example, by temperature fluctuations in an optical fiber, may have the effect that the optical pulses no longer traverse the section having preferred or substantially constant birefringence in one of its main polarization states. By maximizing the transmission quality in repeated, spaced-apart time intervals, one cancels (or reverses) the spreading of the optical pulse caused by the fluctuations.

To allow for the variation over time in the polarization state at the input of the optical communication system, the polarization-controlling device can be connected upstream from the communication system. By regulating the polarization-controlling device, one assures that the section having preferred or substantially constant birefringence is traversed by the optical pulses in one of the two main polarization states of the section, in spite of the birefringence fluctuating over time in magnitude and orientation within the communication system.

To losslessly convert the light into the required polarization state, the polarization-controlling device can include a $\lambda/4$ -, a $\lambda/2$ - and a further $\lambda/4$ delay element, the delay elements being disposed one behind the other and each being adjustable. Using such a polarization-controlling device, light, for example light pulses having any polarization state at all, can be changed into light having a different, desired polarization state.

The polarization-controlling device can also be placed at the output of the communication system, however. This may simplify

the control, since the determination of transmission quality, the control, and the polarization-controlling device are implemented at the same location. To consider only that component of the light which has propagated in the section having preferred or substantially constant birefringence in one of the main polarization states, an analyzer may be additionally configured downstream from the polarization-controlling elements.

If the analyzer is a linear analyzer, then the polarization-controlling device may be simplified to include only a $\lambda/4$ - and a $\lambda/2$ -delay element, each being adjustable, i.e., rotatable. Using a polarization-controlling device of this kind, light having any polarization at all- in this case light transmitted in one of its main polarization states through the portion having preferred birefringence - can be changed into light having a linear polarization - in this case light which is polarized in the transmit direction toward the analyzer.

The delay elements used can include a liquid crystal element or an electro-optic crystal, depending on the special application involved, for example, depending on the wavelength employed. In embodiments of the present invention, the adjusting elements may be readjusted without a driving mechanism, i.e., electrically. If the control takes place at frequencies which are not too high, simple, mechanically movable controlling elements may also be used.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows an exemplary embodiment of the present invention where the polarization-controlling element is positioned upstream from the optical communication system.

Figure 2 shows an exemplary embodiment of the present invention where the polarization-controlling element is placed

the regulating device resets the polarization-controlling element in a direction that is orthogonal to the first direction in the parameter space. This method may lead to a local maximum of the transmission quality in the parameter space of the polarization-controlling element. The method may be repeated in specific intervals, which keeps the transmission quality of the communication system at a high level.

To ascertain the transmission quality, one can use the bit error rate, for example. It may be determined using special measuring instruments and indicates, as a ratio, how many read errors occur in a known sequence of transmitted pulses. Another exemplary embodiment of the present invention is directed to providing for the so-called eye pattern to be used as a measure of the transmission quality of the communication system. In addition, the polarization mode dispersion itself can also be used as a measure of the transmission quality. This may only be determined with relatively substantial outlay, as is the case for the bit error rate and the eye diagram. The exemplary embodiment of the present invention may be directed to using the redundancy monitoring employed in many digital transmission methods to obtain a measure of the transmission error and, thus, of the transmission quality in the communication system.

In the case of the redundancy monitoring, the so-called parity information (parity bytes) may be calculated from the payload to be transmitted, and added to the payload. The parity information may be obtained by performing a simple calculation. It is presently defined for optical communication systems having a synchronous digital hierarchy as the remainder from a quotient formed from the payload code and a preset key code. The parity information may be extracted and any data blocks having faulty information at all points on the optical transmission link where digital analysis of the

device 2. This signal may be conducted via a data line 9,
which essentially runs in parallel to optical transmission
medium 5, as an input signal to regulating device 4. In an
embodiment of the present invention, data line 9 may be a
5 spectral channel of optical fiber 5. The regulating device may
drive polarization-controlling device 3 to change the
polarization of information signal I.

To reduce the distortion, for example, the spreading of
10 information signals, such as of the optical pulses, in
response to the detected transmission quality of communication
system 1, polarization-controlling device 3 is driven by
regulating device 2 to maximize the transmission quality. As a
consequence of the above described control, the light in
15 section 5'' exhibiting the preferred or substantially constant
birefringence has a polarization that corresponds to one of
the main polarization states of the section, so that, within
this region, no distortion occurs, i.e., the signal does not
spread. Thus, with respect to the polarization mode
20 dispersion, that region is "eliminated", which otherwise would
substantially contribute to the distortion of the signal.

To compensate for time-related fluctuations of the
birefringence and consequences resulting therefrom, provision
25 may be made for the transmission quality to be repeatedly
maximized at spaced apart time intervals. In this manner, at
any particular point in time, the light within section 5''
having the preferred or substantially constant birefringence
may be always polarized in parallel to one of the main
30 polarization states of the transmission medium section.

Referring Figure 1, the polarization-controlling device 3
includes a $\lambda/4$ -, a $\lambda/2$ - and a further $\lambda/4$ delay element, these
delay elements being disposed one behind the other and each
35 being adjustable, i.e., rotatable. The three degrees of
freedom of the polarization-controlling device are regulated

by regulating device 4 in accordance with the method of the present invention. Using the entire polarization-controlling device 3, each desired polarization is able to be converted into another desired polarization. Delay elements can include liquid crystal elements, electro-optic crystals, or mechanically, electromotively or piezoelectrically adjustable delay elements, such as fiber loops.

Figure 2 depicts an embodiment of the present invention, where polarization-controlling device 3 is configured downstream from the communication system which includes transmission medium 5 having at least one section 5'' exhibiting a preferred birefringence. Situated in this specific embodiment downstream from the polarization-controlling device, is an analyzer 6, which may absorb or deflect the signal-spreading or signal-distorting polarization components of the optical information flow, depending on the specific embodiment of the analyzer. A small portion of the information flow is split (or separated) off by beam splitter 7 and supplied to detector 8. Its output signal is fed to a regulating device 2, which generates a signal Q that is a measure indicative of the transmission quality. This signal, in turn, is the input quantity for regulating device 4, which drives polarization-controlling device 3. The analyzer 6 may include a linear polarizer, so that the polarization-controlling element merely needs to still transform any particular polarization state into a fixed, linear polarization state. This may be done using a $\lambda/4$ - and a $\lambda/2$ -delay element, which are disposed in series (or one behind the other) and are each adjustable, i.e., rotatable.

The polarization-controlling device may be adjusted when the light which, in the fiber member having preferred or substantially constant birefringence, assumed the one main polarization state, may be imaged onto the light having the transmit polarization of the analyzer, whereas the light,

[illegible]

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2/PRTS

REDUCING THE DISTORTION OF OPTICAL PULSES
CAUSED BY POLARIZATION MODE DISPERSION IN OPTICAL
COMMUNICATION SYSTEMS

The present invention relates to a method for reducing the distortion of optical pulses in optical communication systems, as recited in Claim 1, and to an optical communication system having reduced spreading of the optical pulses propagating through the system, as recited in Claim 5.

In optical communications, optical components, such as optical elements and glass fibers are often used, which are only isotropic in the first approximation, or which are innately anisotropic. For example, the glass fibers employed in photonic networks generally exhibit optical anisotropies due to the manufacturing process and design or due to other circumstances, such as temperature and pressure fluctuations, as well as because of the bending of the fiber itself. These, in part, location-dependent anisotropies also produce an optical birefringence, which can also vary from location to location in the fiber. The birefringence causes two orthogonally polarized natural waves of the light to propagate at different phase velocities in one fiber section under consideration. This means that, in the general case when an optical signal, in particular an optical pulse having any polarization at all, is transmitted through the fiber, the optical pulse becomes distorted, i.e., spreads during the course of propagation, due to the difference in the velocity of the various polarization components. This spreading of the optical pulses limits, in particular, the transmission rate in the communication system.

The object of the present invention is to provide a method for reducing the distortion of optical pulses in optical communication systems caused by polarization mode dispersion, which can be implemented cost-effectively, flexibly adapted to

This technical objective is achieved by the present invention, on the one hand, by the method steps which include the features of Claim 1 and, on the other hand, by the features of Claim 5.

To keep the transmission quality in the optical communication system at an optimal value, the transmission quality is measured, and a signal indicative thereof is applied to a regulating device, which drives a polarization-controlling device to alter the polarization state of the optical pulses. The regulating device controls the polarization of the optical pulses in such a way that the transmission quality is optimized.

Generally, any transmission device at all, for example an optical fiber or other optical component, can be produced with respect to its birefringence properties, from a number of double-refracting plates, each of which has a different, statistically varying birefringence, delay and orientation. A double-refracting plate assembly of this kind is characteristic for a specific wavelength and is, therefore, dependent upon the frequency of the incident light.

The present invention is based on the realization that, for example, an actual glass fiber is generally constituted of a plate assembly, which is not characterized by a stochastic system of double-refracting plates, but rather that there is at least one preferred, i.e., substantially constant birefringence in specific sections of the fiber. This means that the optical properties in the mentioned fiber sections can be specified by a single, thick and/or heavily

However, the extent to which these other sections of the communication system cause the optical pulse to widen is much less than the possible distortion of the pulse within the section having preferred birefringence, for the case that the light does not traverse the last-mentioned section in only one of the main polarization states.

The above explanations apply, on the one hand, for the case when the optical pulses are modified by the polarization-controlling device before entering into the optical communication system, such that the section having preferred birefringence is traversed in one of the main polarization states of the section and, on the other hand, also applies to the case when only that portion of the optical information signal which is transmitted in one of the main polarization states of the section having preferred birefringence, through this section, is considered for the data transmission. Both cases are based on the elucidated principle of the present invention and, accordingly, are equivalent.

To alter the polarization of the information signal in accordance with the present invention, the polarization-controlling device is driven by the regulating device in such a way that the transmission quality is maximized. This regulated, maximal transmission quality corresponds accordingly, for example, to the case when the optical information signal propagates within the section having preferred birefringence in one of the two main polarization states, or when only that portion of the optical information signal, which this applies to, is considered. One advantageous specific embodiment of the present invention provides for repeatedly maximizing the transmission quality at spaced apart time intervals. This makes it possible to diminish the time-related fluctuations in the magnitude and orientation of the birefringence, which can have a negative effect on the distortion of the optical pulses. These

fluctuations, mentioned already above, induced, for example, by temperature fluctuations in an optical fiber, can have the effect that the optical pulses no longer traverse the section having preferred birefringence in one of its main polarization states. By maximizing the transmission quality in repeated, spaced-apart time intervals, one cancels the spreading of the optical pulse caused by the fluctuations.

To allow for the variation over time in the polarization state at the input of the optical communication system, the polarization-controlling device can be connected upstream from the communication system. By regulating the polarization-controlling device, one assures that the section having preferred birefringence is traversed by the optical pulses in one of the two main polarization states of the section, in spite of the birefringence fluctuating over time in magnitude and orientation within the communication system.

To losslessly convert the light into the required polarization state, the polarization-controlling device can include a $\lambda/4$ -, a $\lambda/2$ - and a further $\lambda/4$ delay element, the delay elements being disposed one behind the other and each being adjustable. Using such a polarization-controlling device, light, for example light pulses having any polarization state at all, can be changed into light having a different, desired polarization state.

The polarization-controlling device can also be placed at the output of the communication system, however. This simplifies the control, since the determination of transmission quality, the control, and the polarization-controlling device are implemented at the same location. To consider only that component of the light which has propagated in the section having preferred birefringence in one of the main polarization states, an analyzer is additionally configured downstream from the polarization-controlling elements.

If this analyzer is a linear analyzer, then the polarization-controlling device is simplified to the effect that it includes only a $\lambda/4$ - and a $\lambda/2$ -delay element, which are each adjustable, i.e., rotatable. Using a

5 polarization-controlling device of this kind, light having any polarization at all- in this case light transmitted in one of its main polarization states through the portion having preferred birefringence - can be changed into light having a linear polarization - in this case light which is polarized in
10 the transmit direction toward the analyzer.

In both the arrangements that make use of the principle of the present invention, as well as in the method, the delay elements used can include a liquid crystal element or an electrooptic crystal, depending on the special application
15 involved, for example depending on the wavelength employed. The advantage of these adjusting elements is that they can be readjusted without a driving mechanism, i.e., electrically. If the control takes place at frequencies which are not too high, simple, mechanically movable controlling elements can also be
20 used.

The present invention is described in the following on the basis of a few exemplary embodiments, reference being made to the drawing, whose figures show:

25 Figure 1 one specific embodiment of the present invention, where the polarization-controlling element is positioned upstream from the optical communication system; and

Figure 2 one specific embodiment of the present invention,
30 where the polarization-controlling element is placed at the output end of the communication system.

In accordance with the present invention, the optical communication system having reduced distortion of the optical
35 pulses passing through the system includes an optical transmission medium that is composed of various sections. These can include optical components, such as fiber couplers,

Another specific embodiment of the present invention provides for the so-called eye pattern to be used as a measure of the transmission quality of the communication system. In addition, the polarization mode dispersion itself can also be used as a measure of the transmission quality. However, this can only be determined with relatively substantial outlay, as is the case for the bit error rate and the eye diagram. For that reason, most specific embodiments of the present invention make use of the redundancy monitoring employed in many digital transmission methods to obtain a measure of the transmission error and, thus, of the transmission quality in the communication system.

In the case of the redundancy monitoring, the so-called parity information (parity bytes) are calculated from the payload to be transmitted, and added to the payload. The parity information is obtained by performing a simple calculation. It is presently defined for optical communication systems having a synchronous digital hierarchy as the remainder from a quotient formed from the payload code and a preset key code. One can extract the parity information and immediately recognize data blocks having faulty information at all points on the optical transmission link where digital analysis of the signals is possible. In contrast to the bit error rate, the described redundancy monitoring only permits one data block error rate to be determined, since each parity byte has assigned to it one complete data record which, accordingly, can only be checked as a whole. Since typically, however, in the case of signal distortion, i.e., in the case of optical pulse spreading due to polarization mode dispersion, no so-called burst errors occur, i.e., the errors are distributed more or less equally over time, the redundancy monitoring and a signal Q derived therefrom as an input signal are suited for the regulating device.

Figure 1 depicts an exemplary specific embodiment of an optical communication system 1 in accordance with the present invention having reduced distortion of the information signal propagating through the system. The optical information signal is transmitted in the form of optical pulses through a polarization-controlling element 3, before entering into the optical transmission medium 5. This optical transmission medium 5 includes various sections 5', 5'', 5''', in the present example, section 5'' being a section in which a preferred birefringence occurs. In the present instance, the optical transmission medium is constituted of an optical fiber line. The other sections 5', 5''' exhibit a stochastic distribution with respect to the birefringence. Accordingly, these regions are able to be characterized by a random arrangement of double-refracting plates. Behind the transmission medium, the optical information signal, for example an optical pulse, is incident to a beam splitter 7, which couples out a small portion of the communication-transmitting luminous flux. A detector 8 converts the coupled-out portion of the information signal into an electric signal, which is applied to a device 2 for determining the transmission quality of communication system 1. By way of the above described redundancy monitoring, a signal Q, which is a measure of the transmission quality, is generated in device 2. This signal is conducted via a data line 9, which essentially runs in parallel to optical transmission medium 5, as an input signal to regulating device 4. In one specific embodiment of the present invention, data line 9 is a spectral channel of optical fiber 5. The regulating device drives polarization-controlling device 3 to change the polarization of information signal I.

To reduce the distortion, for example the spreading of information signals, i.e., of the optical pulses, in response to the detected transmission quality of communication system 1, polarization-controlling device 3 is driven by regulating device 2 to maximize the transmission quality. As a

To compensate for time-related fluctuations of the birefringence and consequences resulting therefrom, provision is made for the transmission quality to be repeatedly maximized at spaced apart time intervals. In this manner, at any particular point in time, the light within section 5'' having the preferred birefringence is always polarized in parallel to one of the main polarization states of the transmission medium section.

The polarization-controlling device 3 in Figure 1 includes a $\lambda/4$ -, a $\lambda/2$ - and a further $\lambda/4$ delay element, these delay elements being disposed one behind the other and each being adjustable, i.e., rotatable. The three degrees of freedom of the polarization-controlling device are regulated by regulating device 4 in accordance with the above method. Using the entire device 3, each desired polarization is able to be converted into another desired polarization. Delay elements can include liquid crystal elements, electrooptic crystals, or mechanically, electromotively or piezoelectrically adjustable delay elements, such as fiber loops.

Figure 2 depicts one specific embodiment of the present invention, where polarization-controlling device 3 is configured downstream from the communication system which includes transmission medium 5 having at least one section 5'' exhibiting a preferred birefringence. Situated in this specific embodiment downstream from the polarization-controlling device, is an analyzer 6, which

absorbs or deflects the signal-spreading or signal-distorting polarization components of the optical information flow, depending on the specific embodiment of the analyzer. A small portion of the information flow is split off by beam splitter 7 and supplied to detector 8. Its output signal is fed to a regulating device 2, which generates a signal Q that is a measure of the transmission quality. This signal, in turn, is the input quantity for regulating device 4, which drives polarization-controlling device 3. In the described specific embodiment of the present invention, analyzer 6, as described above, includes a linear polarizer, so that the polarization-controlling element merely needs to still transform any particular polarization state into a fixed, linear polarization state. This can be done using a $\lambda/4$ - and a $\lambda/2$ -delay element, which are disposed in series and are each adjustable, i.e., rotatable.

The polarization-controlling device is optimally adjusted when the light which, in the fiber member having preferred birefringence, assumed the one main polarization state, is imaged onto the light having the transmit polarization of the analyzer, whereas the light, which assumed the other polarization state, is imaged onto the light having the blocking polarization state of the linear polarizer. The light which is imaged onto the transmit polarization of the analyzer should preferably exhibit the higher intensity portion of the entire signal intensity. For this reason, the control unit is set up such that, in response to too low optical intensity of the information flow downstream from the analyzer, it switches over to the other main polarization direction of the section of the communication system, preferably fiber member 5", having the preferred birefringence.

In place of beam splitter 7 and detector 8 in Figures 1 and 2, another specific embodiment of the present invention provides that the transmission quality be measured at the same time that the information itself is detected, directly by the main

[illegible]

1. A method for reducing the distortion of optical pulses (I) in an optical communication systems (1) caused by polarization mode dispersion, wherein, functioning in response to the detected transmission quality of the communication system, a polarization-controlling device (3) for adjusting the polarization of the optical pulse is driven in such a way that the transmission quality is maximized.
2. The method as recited in Claim 1, wherein, to optimize the communication, the polarization is reset in predefined time intervals.
3. The method as recited in Claim 1 or 2, wherein the polarization of the optical signal (I) is controlled at the beginning of the optical communication system.
4. The method as recited in Claim 1 or 2, wherein, using the polarization-controlling device (3), the polarization of the optical pulses is altered at the end of the optical communication system (5), and, following the optical communication system, the signal (I) propagates through an analyzer (6).

Abstract

Reducing the distortion of optical pulses caused by the polarization mode dispersion in optical communication systems.

5

When an optical pulse having any polarization at all is transmitted through an optical communication system, which is optically anisotropic, at least in sections, the optical pulse generally becomes distorted due to the different velocities of the various polarization components. This distortion of the optical pulses reduces, in particular, the maximum transmission rate of the system.

A remedy is provided, on the one hand, by a method where, functioning in response to the detected transmission quality of the communication system, a polarization-controlling device for setting the polarization of the optical pulse is driven in such a way that the transmission quality is maximized and, on the other hand, by an optical communication system, which includes an optical transmission medium, a device for determining the transmission quality of the communication system, a regulating device, and a polarization-controlling device. The output signal from the device for determining the transmission quality of the communication system is applied to the regulating device, which drives the polarization-controlling device to change the polarization of the optical pulses in such a way that the transmission quality is optimized.

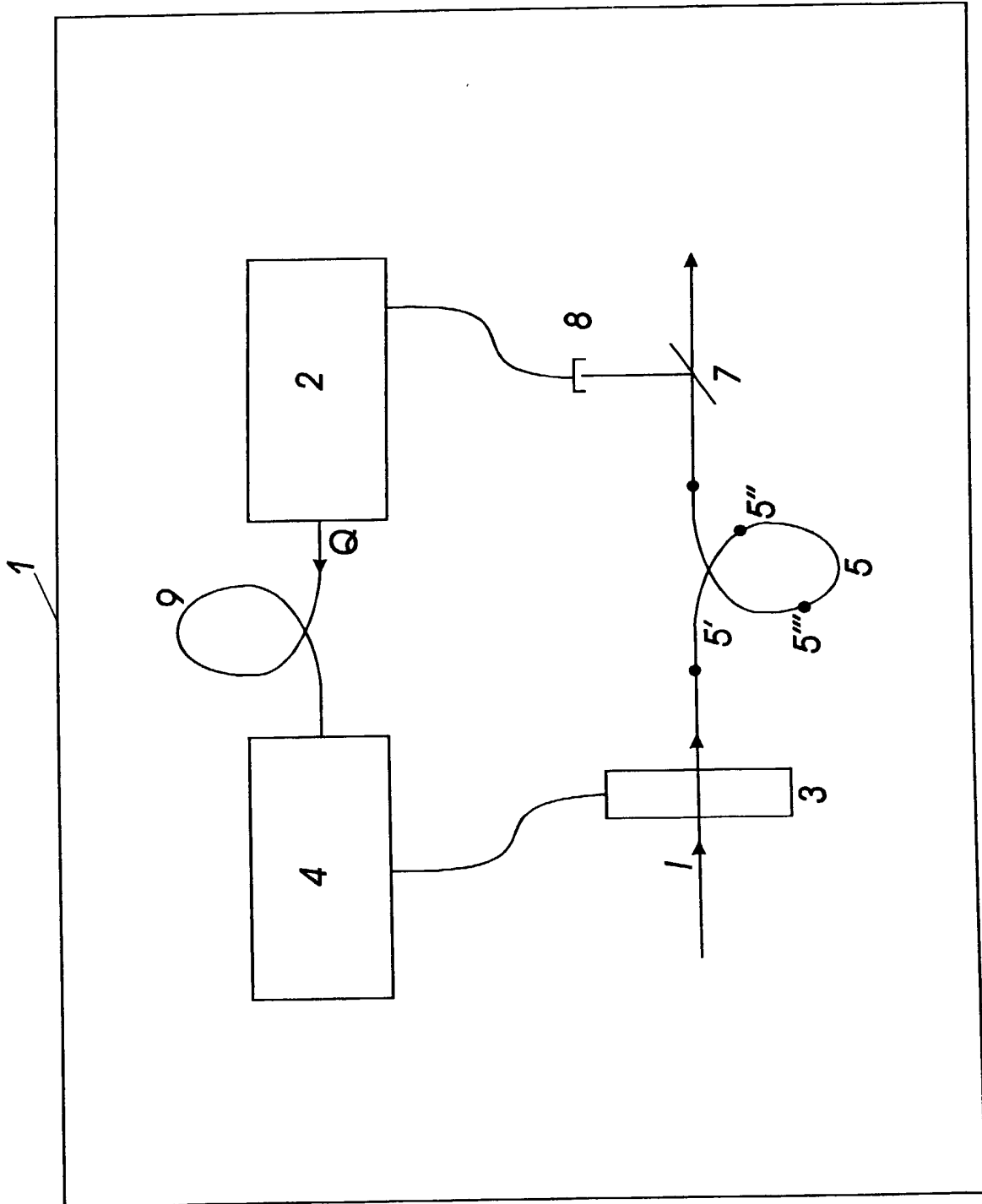


Fig. 1

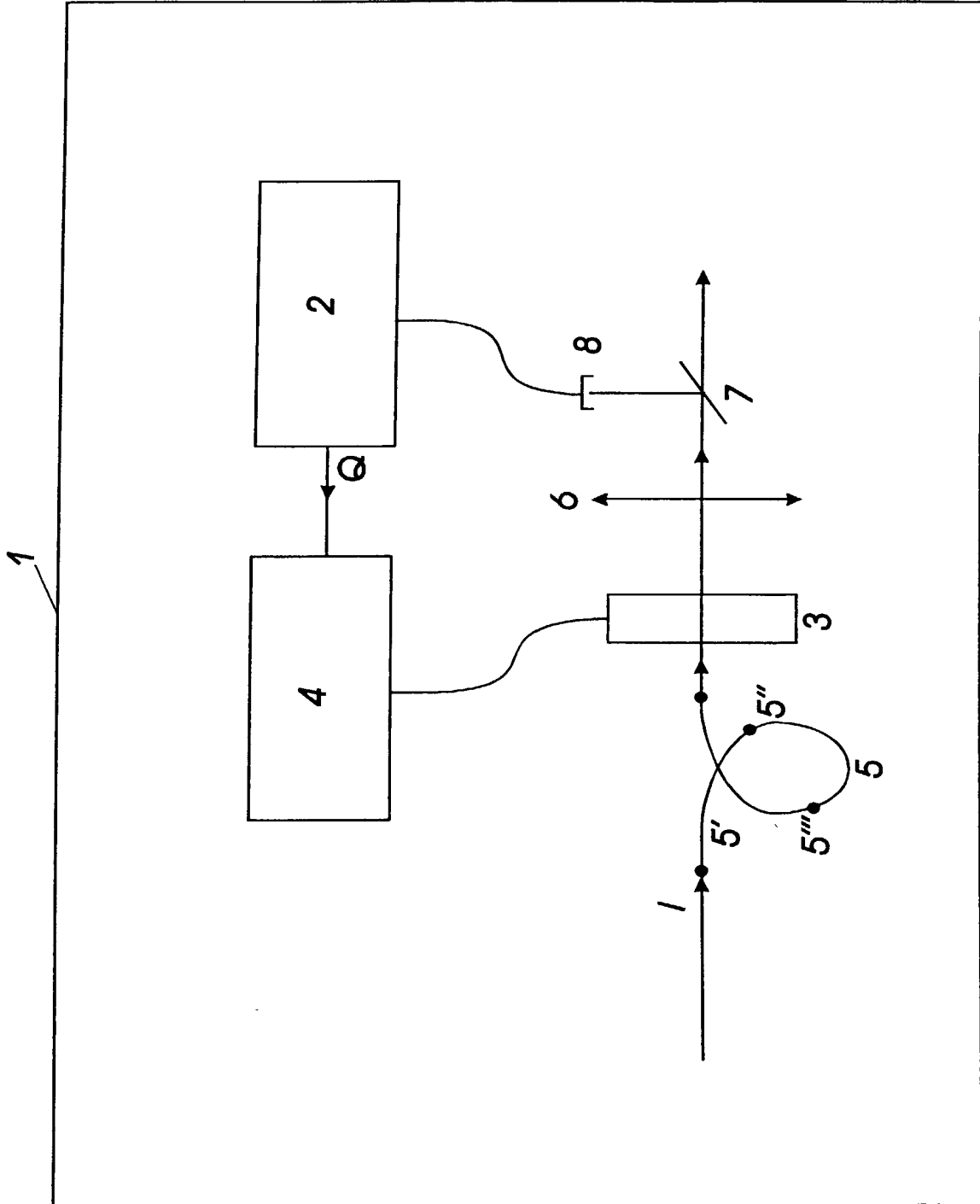


Fig. 2

DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that:

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I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled **REDUCTION OF THE DISTORTION OF OPTICAL IMPULSES THROUGH POLARISATION MODE DISPERSION IN OPTICAL TRANSMISSION SYSTEMS**, the specification of which was filed as International Application No. PCT/EP00/00320 on January 17, 2000 and filed as a U.S. application having Serial No. 09/890597 on August 3, 2001 for Letters Patent in the U.S. Patent and Trademark Office.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, § 1.56(a).

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PRIOR FOREIGN APPLICATION(S)

Number	Country Filed	Day/Month/Year	Priority Claimed Under 35 USC 119
199 04 137.7	Fed. Rep. of Germany	February 3, 1999	Yes

3/ And I hereby appoint Richard L. Mayer (Reg. No. 22,490), Gerard A. Messina (Reg. No. 35,952) and Linda M. Shudy (Reg. No. 47,084) my attorneys with full power of substitution and revocation, to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith.

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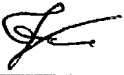
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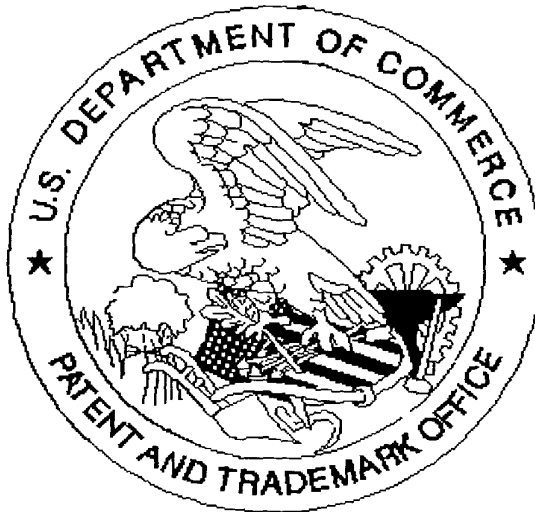
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